Reducing Mass of Steel Auto Bodies Using Thin Advanced High-Strength Steel with Carbon Fiber Reinforced Epoxy Coating

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Oak Ridge National Laboratory
National Transportation Research Center

2017 U.S. DOE Vehicle Technologies Office
Annual Merit Review

June 6, 2017 **Project ID: MAT144**

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Overview

Timeline

- Project start: 3 April 2018
- Project end: 30 March 2020
- Percent complete: 10%

Barriers

- Low Cost, High Volume Manufacturing
- Use of Multi-Material solutions
- Novel Design Approaches

Budget

- Total project funding
  - DOE share: $300,000
  - Contractor share: $339,000
- FY 2017 funding: $300,000
- FY 2018 funding: $0

Partners

- Diversitek (Rajan Eadara)
- ArcelorMittal (Michael Lizak) (Sriram Sadagopan)
- ORNL (C. David Warren, Donovan Leonard)
- INL (Gabriel Ilevbare)
- Project lead: Rajan Eadara

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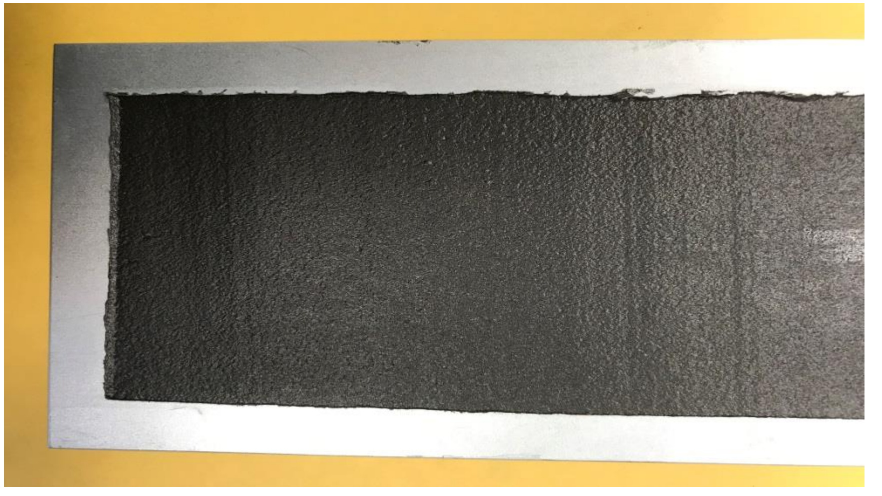
Relevance/Objectives

<u>Objectives</u>: Develop carbon fiber filled formulated epoxy composite materials which when applied to steel allow the use of lower thickness AHSS (down gauging) thus reducing component mass.

- A robotically dispensed paste applied with spray, swirl, or shovel applications
- Cures at 150ºC to 200ºC temperatures
- The material forms into a high modulus coating on steel substrates
- Target: closure panel materials 0.6mm BH240 and DP 490
- Achieve the same structural performance while reducing the weight of the steel panel by down gauging
- >15% reduction in component mass
  - Doors
    - 0.6mm DP490
    - 0.55mm DP490
    - 0.5mm DP490



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Approach

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- Year 1: Determine the optimal (performance and cost) fiber concentration, fiber size, fiber source, application method, application speed and cure temperatures.
  - ArcelorMittal: Part design, steel fabrication, corrosion performance.
  - Diversitek: Coating composition and application.
  - ORNL: Fiber selection, SEM analysis, CTE determination, Coating Evaluation.
  - INL: Corrosion performance at coupon and full scale levels.
- Year 2: Characterize corrosion performance and apply technology to real parts for performance evaluation

Key: Milestone Completed

Task/MS	Milestone Description	Due
1	Delivery of fiber to Diversitek	**April 2018**
2	Demonstration panels produced and fiber distribution determined. Metric a 15% reduction in sheet mass/ square unit area with equivalent stiffness.	**December 2018**
3	Application process set-up and demonstration of the pilot scale unit.	April 2019
4	Industry test data quantifying adhesion and listing any deficiencies.	June 2019
5	Test data comparing the CFRE coated steel with uncoated steel.	October 2019
6	Final Project Report and commercialization plan.	April 2020

Approach/Project Schedule

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Task/MS	Milestone Description (Continued)	Due
7	Initial corrosion assessment of panels and body panels. SAE J2334	October 2019
8	Environmental corrosion assessment of coupons and body panels.	December 2019
9	Humidity corrosion assessment of door assemblies and panels.	April 2020

Task Number & Brief Description	**Year 1**				**Year 2**			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Material Selection								
Task 2: Pilot Scale Demonstration								
Task 3: Steel Evaluation								
Task 4: CFRE Evaluation								
Task 5: Cost Analysis								
Task 6: Scale-Up Planning and Demonstration								
Task 7: SAE J2334 Corrosion Coupon Testing and Body Panels								
Task 8: Environmental Corrosion Testing Coupons and Body Panels								
Task 9: Humidity Corrosion Testing Body Panels								

Collaboration and Coordination

ArcelorMittal	Prime	Industry	Lead on Steel and Components, Provide steel sheets and components and conduct performance specifications.
Diversitek	Prime	Industry	Lead on CFE and Panels, Developing Application of Composite and composite formulation.
ORNL	LightMAT	National Laboratory	Lead on Materials Evaluation, SEM, CTE measurements, Composite characterization.
INL	LightMAT	National Laboratory	Lead on Corrosion Testing of panels and components.

Technical Accomplishments

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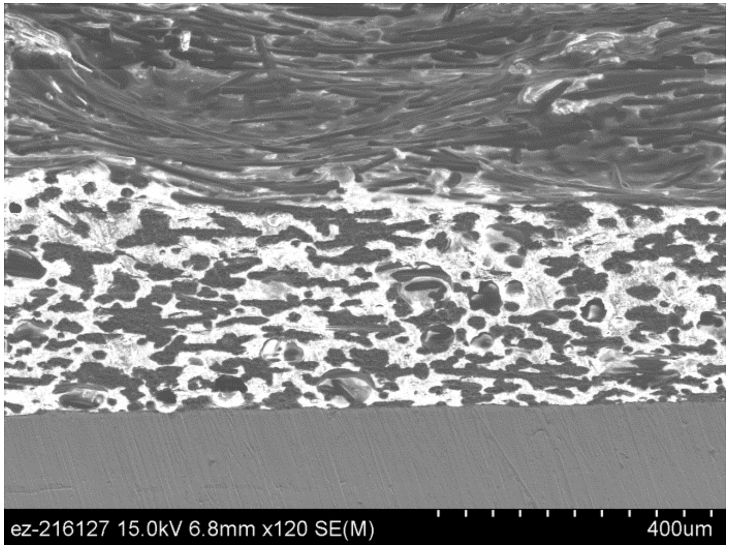
Material Development is near completion

- The Material is designed to meet a broad spectrum of performance requirements
  - Low Coefficient of the thermal expansion
  - Corrosion resistance – Durability
  - No morphology change in thermal cycling

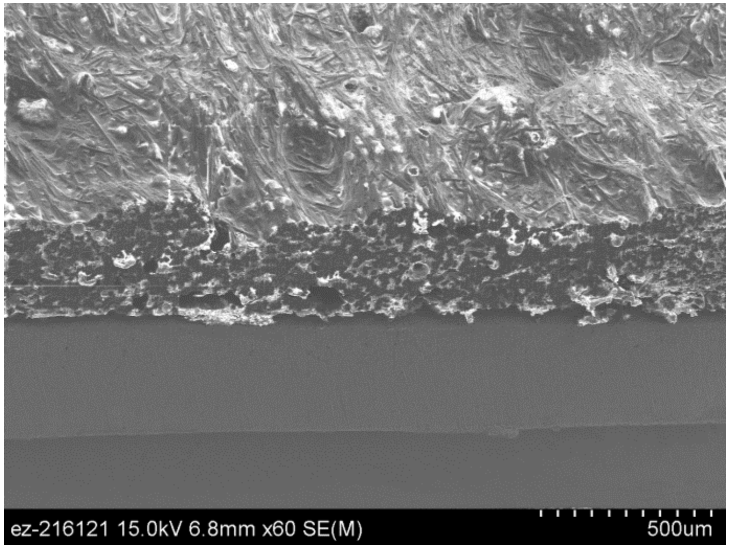
Material Properties of the Composite	
Density	0.9 +/- 0.05 g/cc
Shelf Life	3 months when stored below 38°C and away from sources of heat and sunlight
Adhesion Lap Shear Strength 23°C/ 80°C/ -40°C	16 Mpa/ 14 Mpa/ 18 MPa
Peel Strength	6,500 N/M
Cold Adhesion (SAE J243, ADS-2)	No flaking & No loss of adhesion
Wash Resistance (CILTM 9090, 2000psi)	No measurable movement, displacement or wash off
Application Method	Robotically spray, swirl or shovel.
Cure Temperature	150-200°C
Tensile Strength	40 MPa
Elongation at Break	3 – 5%
Modulus	4.5 – 5.0 GPa
E-Coat Compatibility	Rating 10 – No clusters
Dimpling Test (CEPT 01.00 L-200)	70+ lbs

Technical Accomplishments: SEM Evaluation

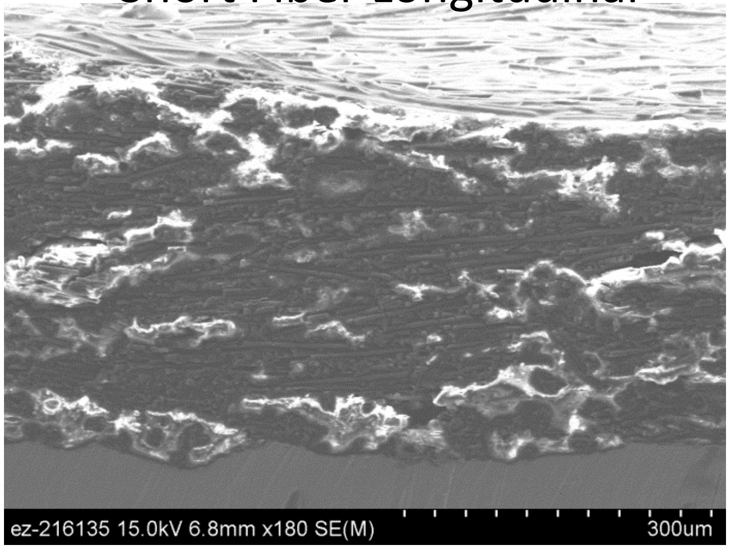
Long Fiber Longitudinal



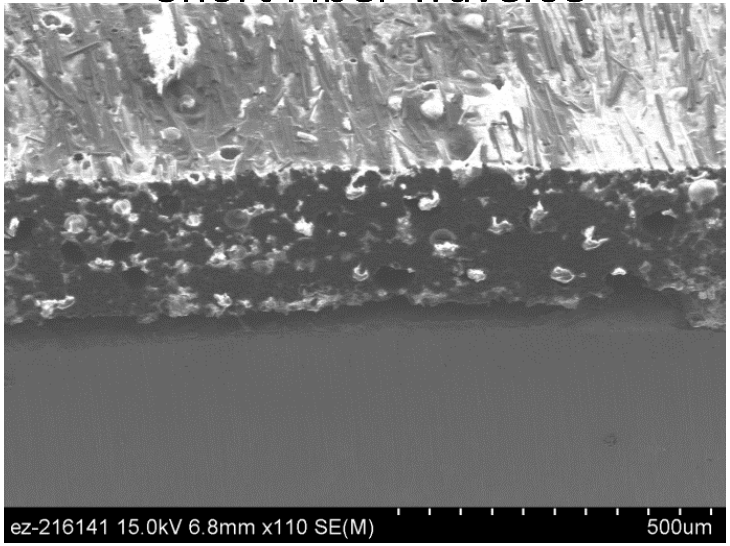
Long Fiber Traverse



Short Fiber Longitudinal



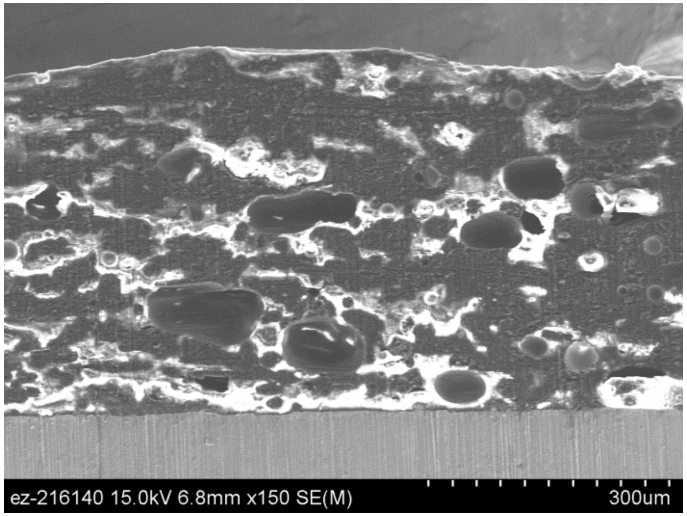
Short Fiber Traverse



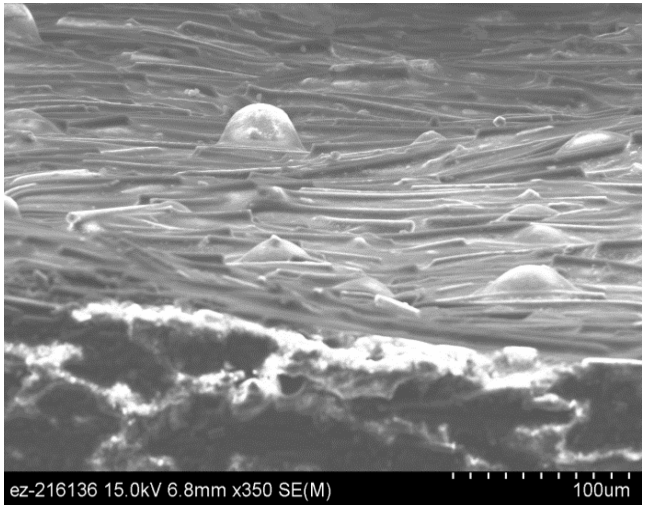
Definite tendency for the fibers to be aligned along the direction of the spray nozzle feed.

Technical Accomplishments: SEM Evaluation

A significant amount of voids were noted throughout the samples, likely due to outgassing of the epoxy as it cures. Void concentration increased with fiber length – likely due to a nesting effect.

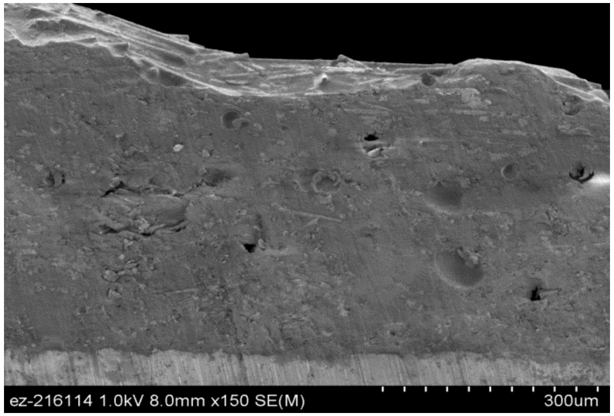


Internal Voids

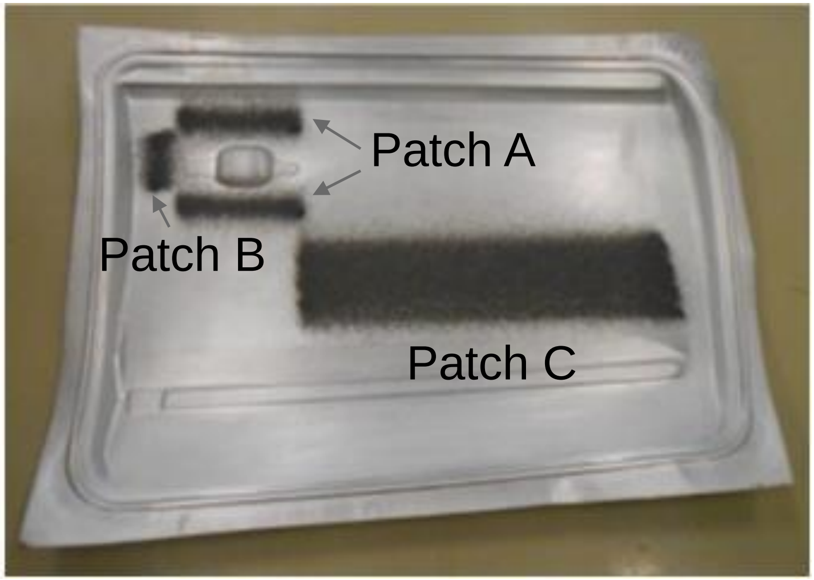


Surface Voids

Steel/Coating Interface



Reinforcement Application Areas



Selective Reinforcement
Mass addition to door (gm)

	0.5mm	1.0mm
Patch A	12.58	25.16
Patch B	5.24	10.48
Patch C	97.29	194.58
Total	115.11	230.22

Complete coverage of door

- Mass Added ~450 gm

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Technical Accomplishments

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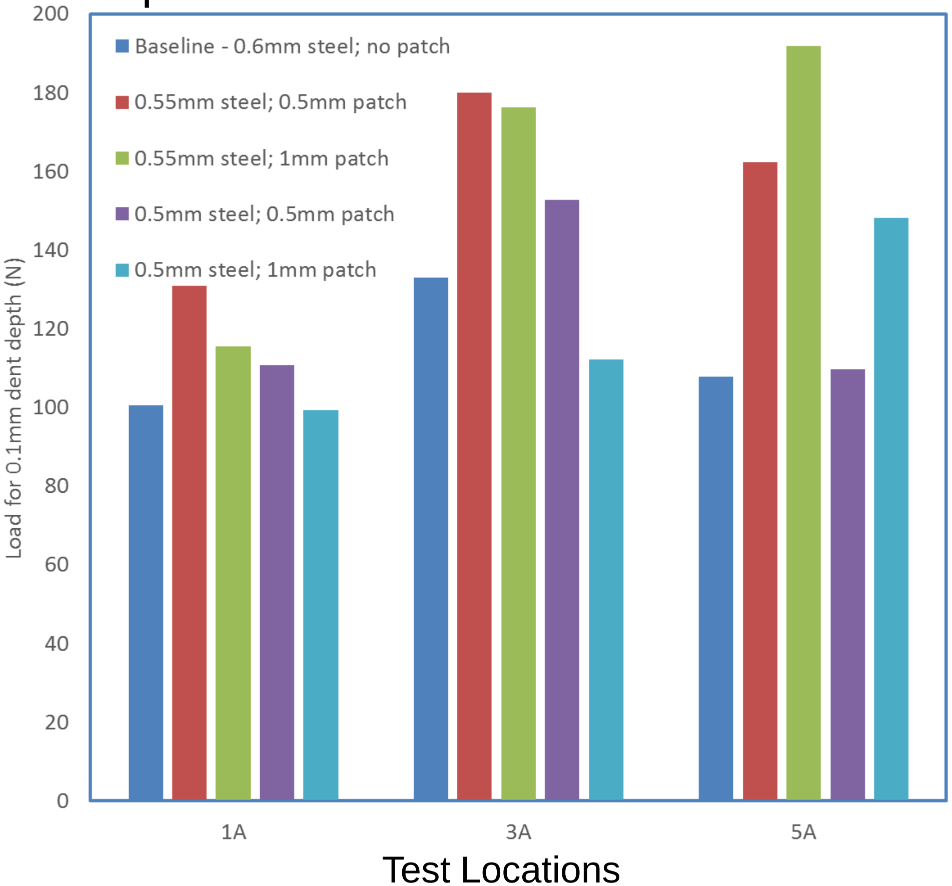
Completed Selection of Fiber Concentration and Size

Material Thickness	Steel Thickness: 0.60 mm	0.66 mm	0.70 mm	0.80 mm	0.93 mm
0 mm	25 N	30 N	35 N	42 N	52 N
0.5 mm	40 N	45 N	50 N	55 N	70 N
1.0 mm	60 N	65 N	70 N	80 N	95 N
2.0 mm	100 N	115 N	120 N	130 N	135 N

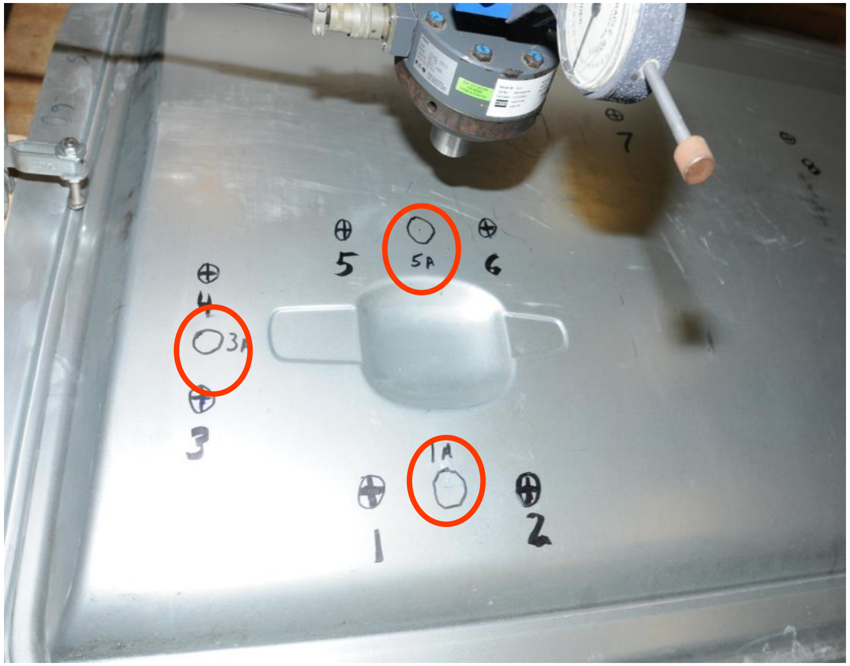
A fiber length and concentration in the epoxy was chosen. (specific formulation omitted for proprietary reasons) Recycled carbon fiber is being used.

Technical Accomplishments: Dent and Oil Canning Testing

Dent Test Results
Comparison with a mass-efficient baseline



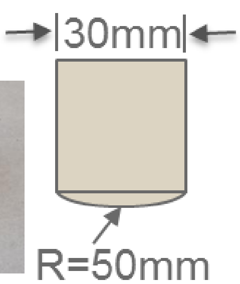
Dent resistance of 0.5mm door skin with reinforcement was comparable to the baseline of 0.6mm



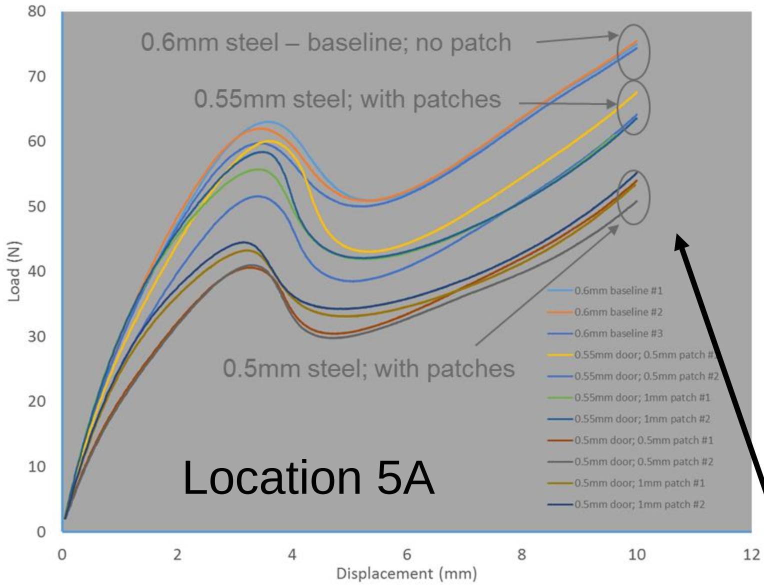
25.4 mm Hemispherical (Point Load)

Dent testing indenter

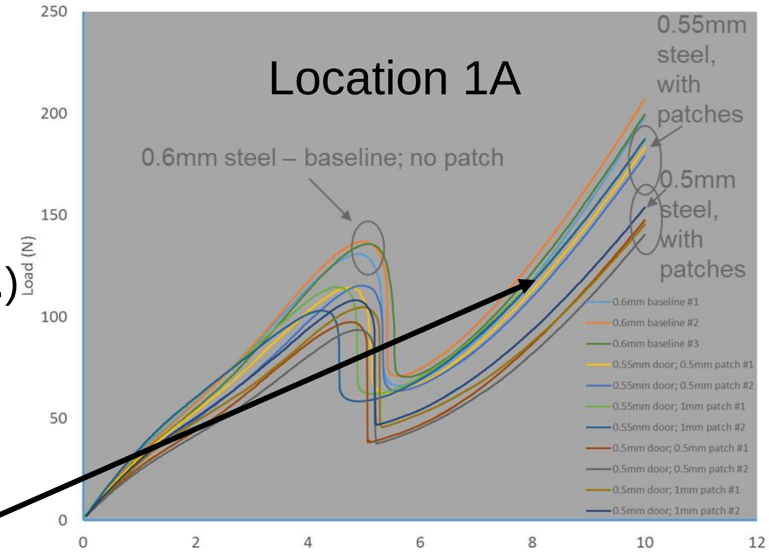
Oil canning indenter (Distributed Load)



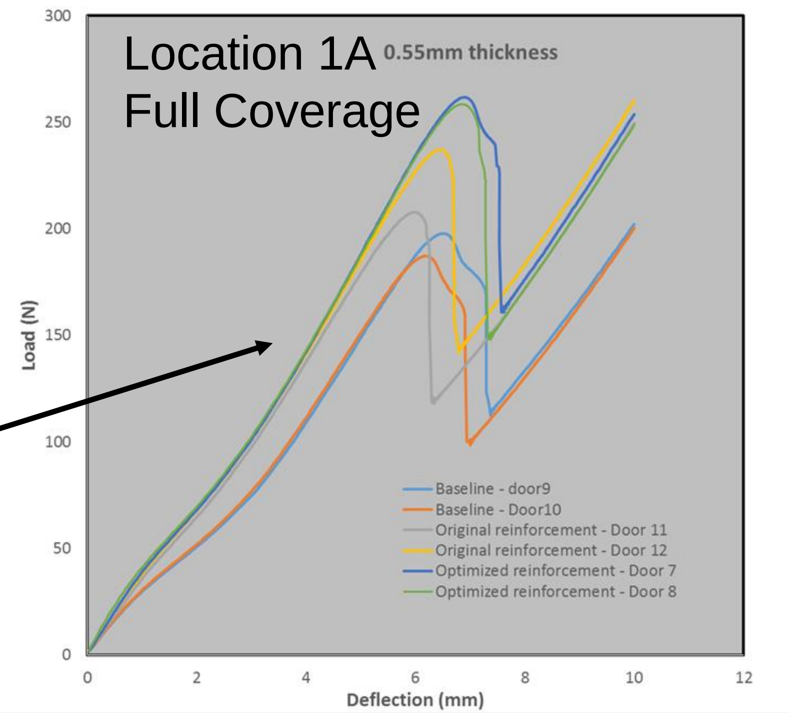
Dent and Oil Canning Testing (Continued)



(Higher Load at a displacement indicates more oil canning resistance.)

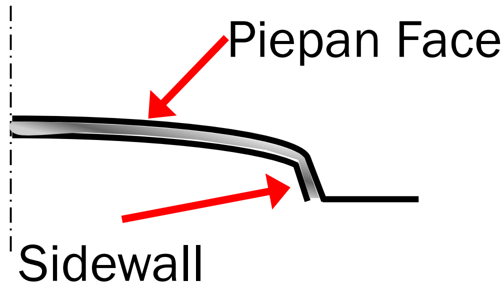


- Use of local patches are not effective in increasing oil canning resistance
- Need to increase CFRE coverage area to meet oil canning requirement

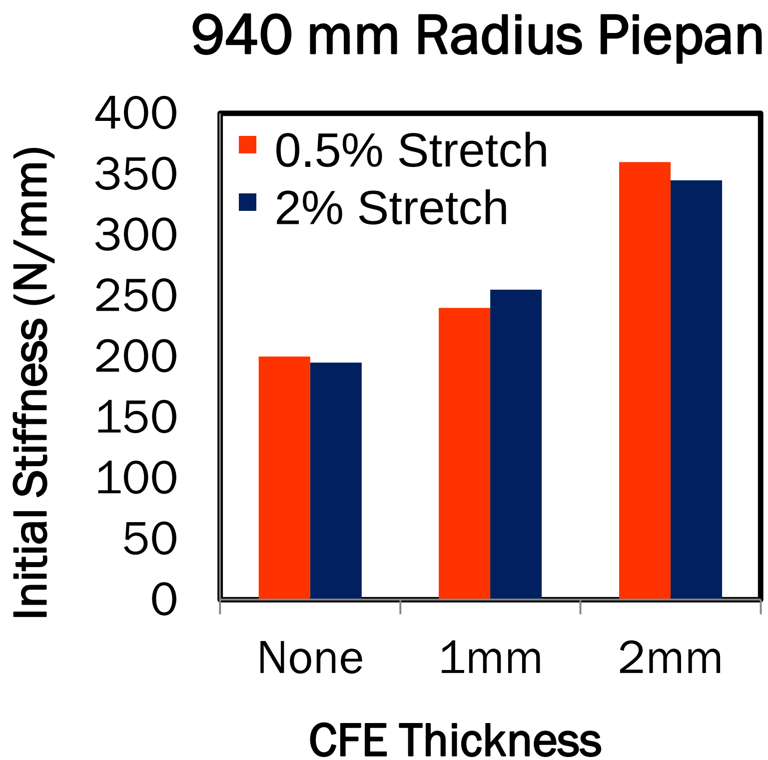


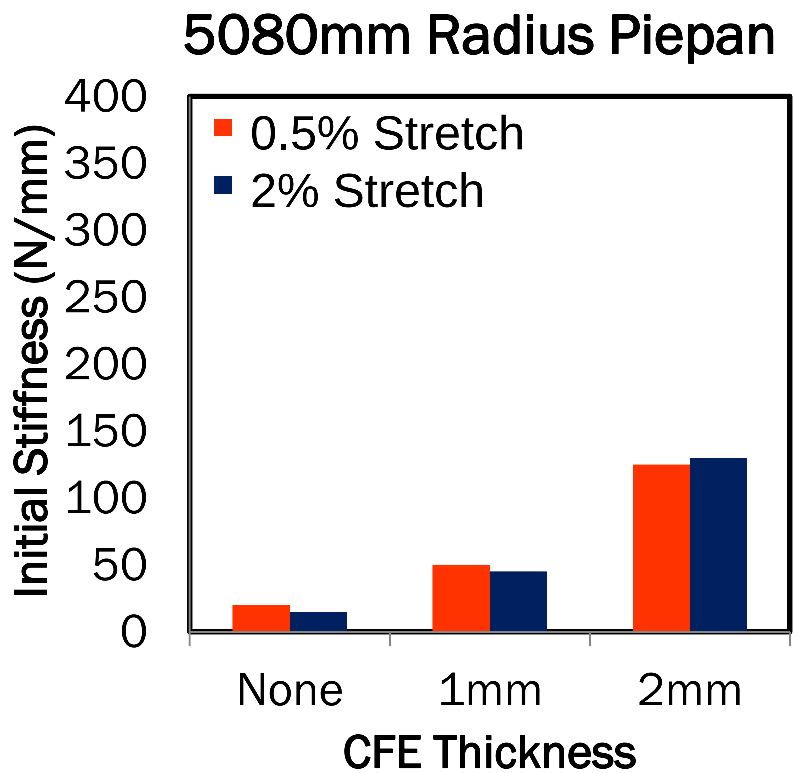
- Full Coverage CFRE application results in better oil canning performance.
- Further Formulation optimization increased this effect.

Technical Accomplishments: Bending Stiffness



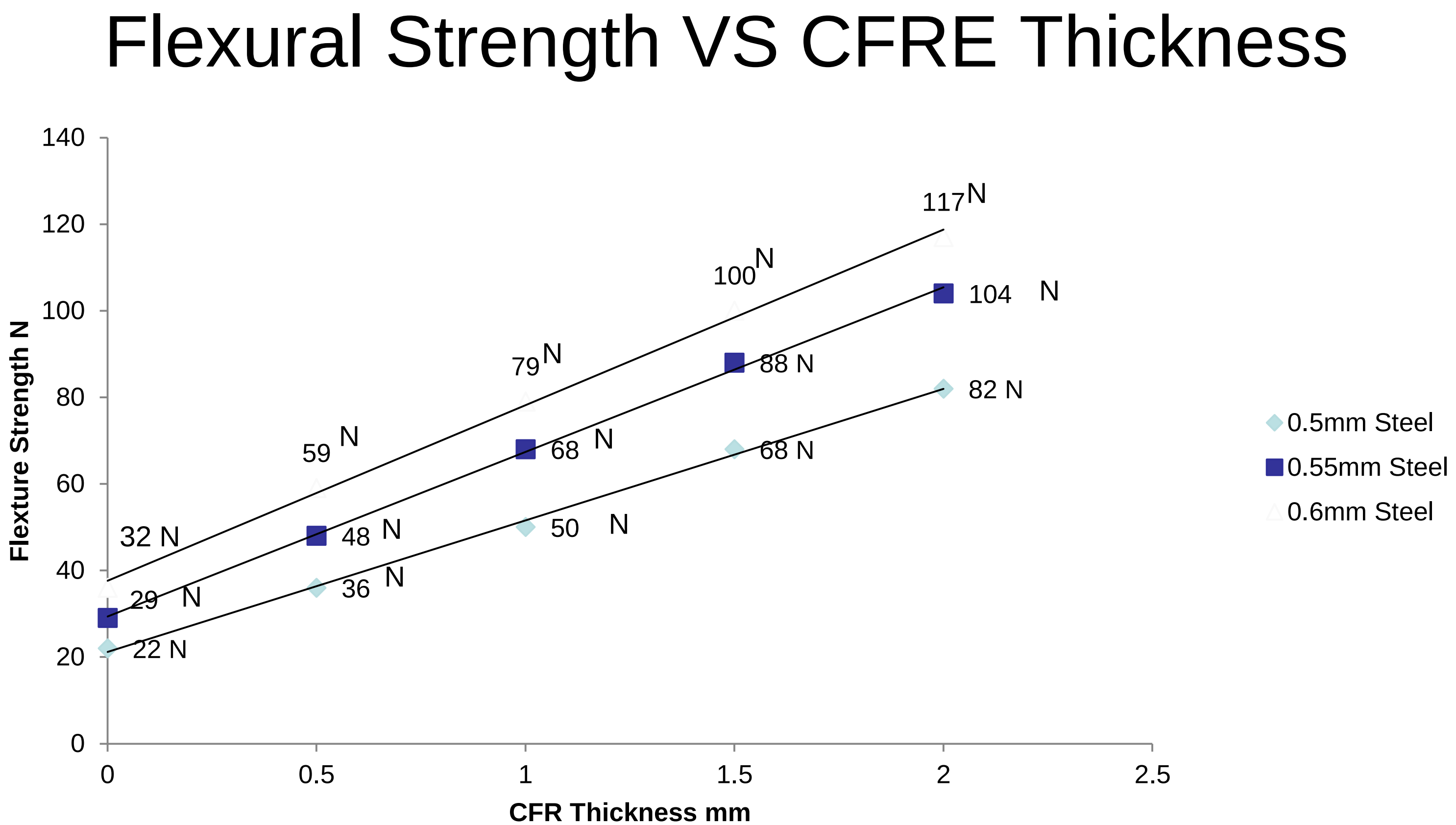
- Application of CF Epoxy
  - Thickness - 1mm & 2mm
  - Application area - Piepan face + sidewall

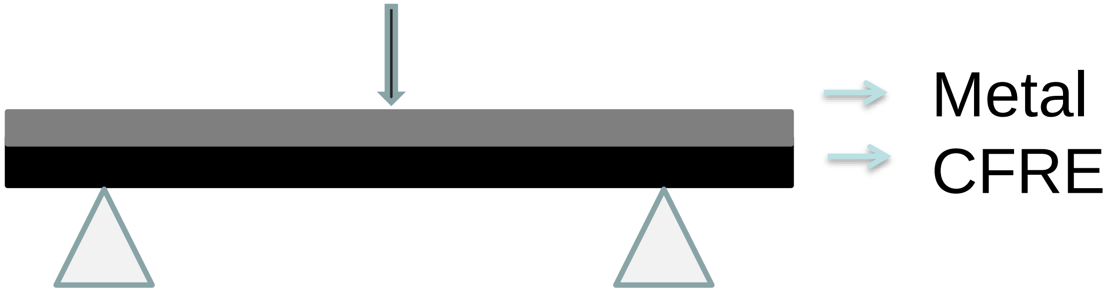




- Initial stiffness was enhanced by use of the reinforcement coating

Technical Accomplishments: Flexural Strength





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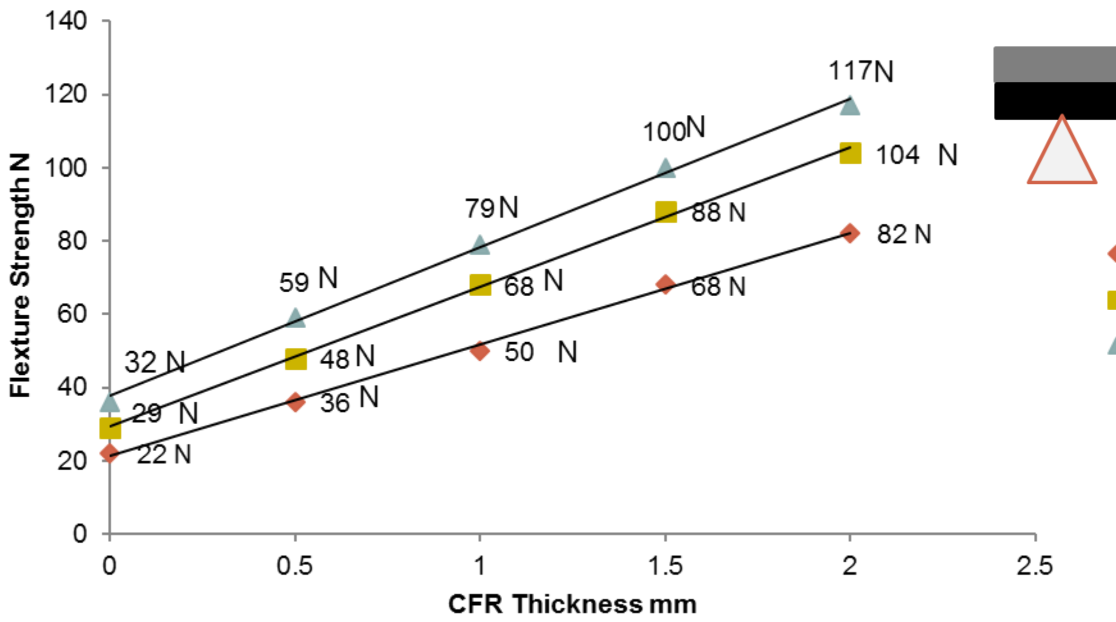
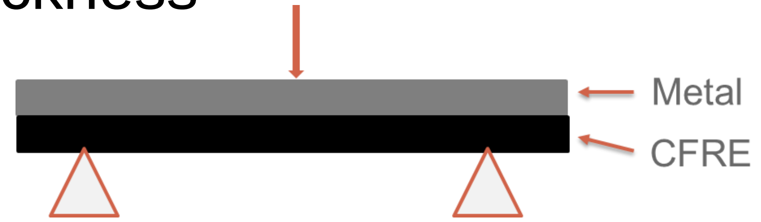
Technical Accomplishments: Flexural Strength & CTE

Flexural Strength VS CFRE Thickness

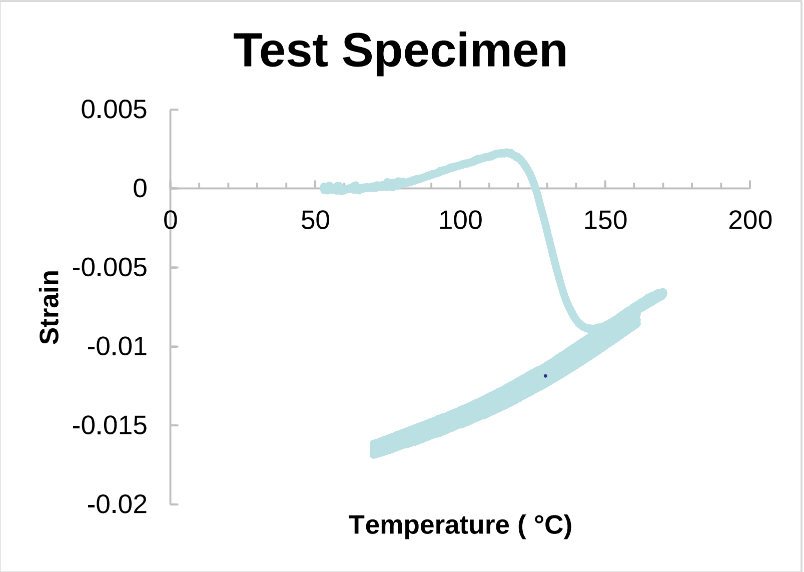




Linear relationship between flexural strength and CFRE thickness

CTE Measurement: Plot of strain as a function of temperature during three heating/cooling cycles for test specimen. Contraction of the test specimen commenced at 120°C and ended at 145°C during the first cycle. The most likely mechanisms responsible for this behavior if temperature-induced curing.

Samples were compression molded, 3D samples are being made for a more accurate analysis.



Proposed Future Research

Now that a final formulation has been determined:

- Complete Panel Level SEM Evaluation of Panels (2018)
- Complete CTE evaluation in each of three directions. (2018)
- Begin Corrosion Testing of Panels (2018-2019)
- Design Production System for Application (2018)
- Construct Production System (2019)
- Integrate Material Property information into Design Models (2019)
- Produce Component Door Parts for Full Scale Testing (2018)
- Conduct Component Full Scale Testing (2019)
- Corrosion Testing of Door Parts (2019-2020)
- Conduct Cost and Mass Study (2019-2020)

Summary Slide

- Epoxy system, fiber length, fiber concentration, and fiber source have been determined.
- Application method has been developed.
- Significant increases in stiffness, dent resistance and oil canning resistance have been quantified.
- Mass reduction potential has been demonstrated.
- Initial CTE measurements and SEM analysis have been conducted.
- Project is well ahead of schedule.

Technical Back-Up Slides

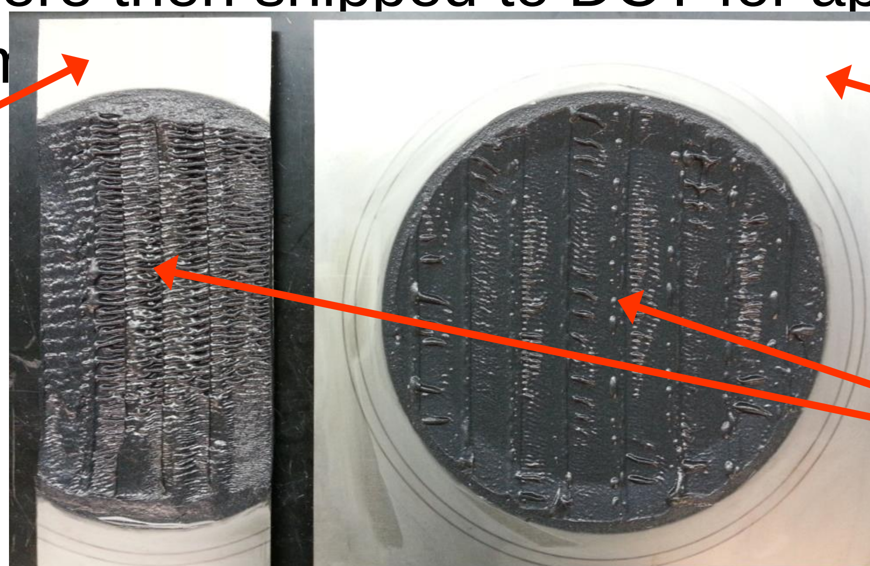
Material Properties

YS (MPa)	TS (MPa)	UE (%)	TE (%)	n-value	R-bar
272	383	21.3	37	0.207	1.2

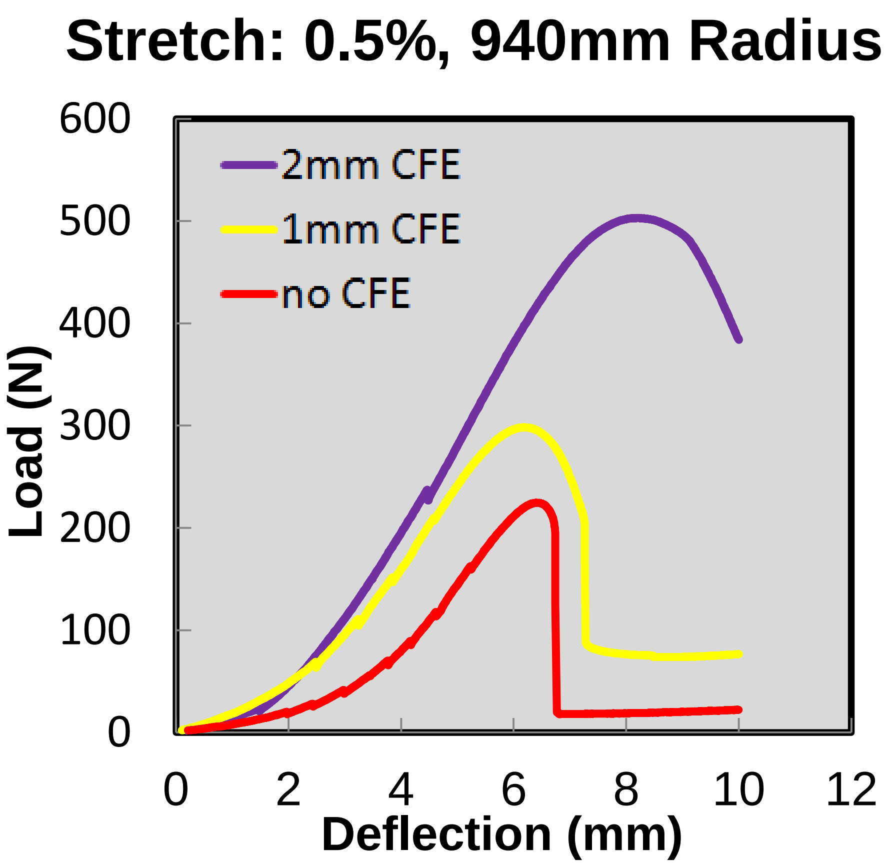
- Selected Properties of CF Epoxy
  - Color: Black
  - Lap Shear Strength: 16.4MPa
  - As Received Peel Resistance: 7800 N/m
  - Application Methods: Paste, Swirl, or Shovel
  - Viscosity at room temperature: 80 sec.

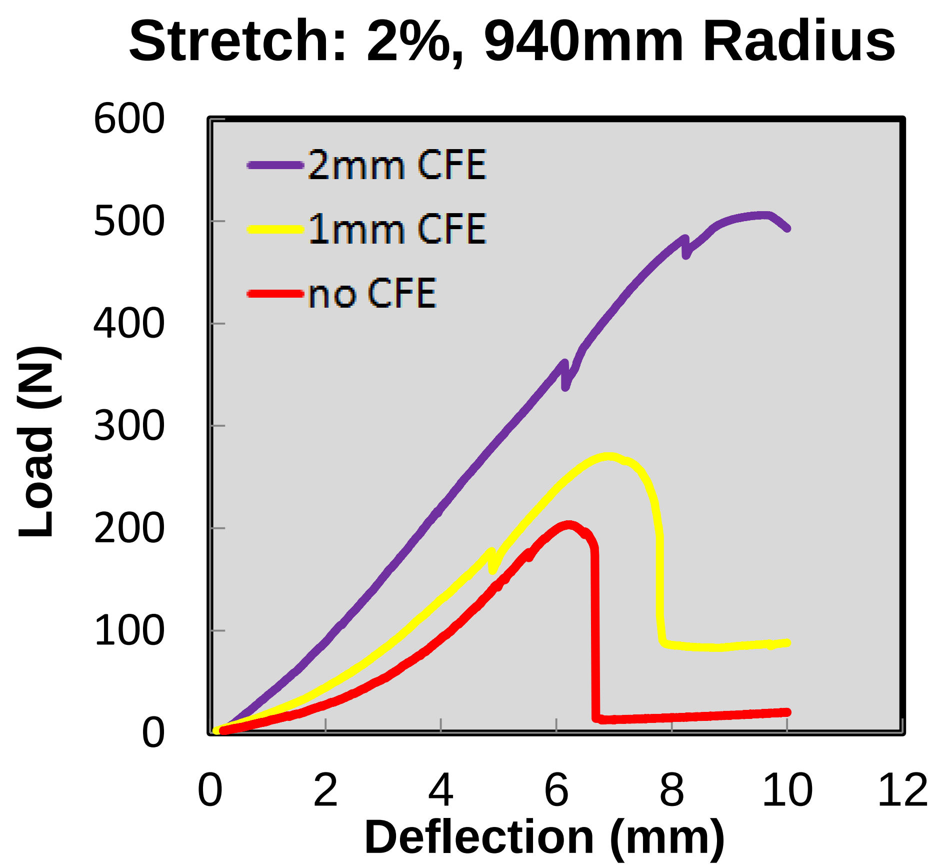
Factors Affecting Performance

- Piepans were formed to achieve a biaxial stretch of 0.5% and 2%
- Radii of curvature of piepans: 940mm, 5080mm
- Half the piepans were cut to enable oil canning testing
- Piepans were then shipped to DCT for application of the Reinforcem surface



Experimental Results: Oil Canning Resistance

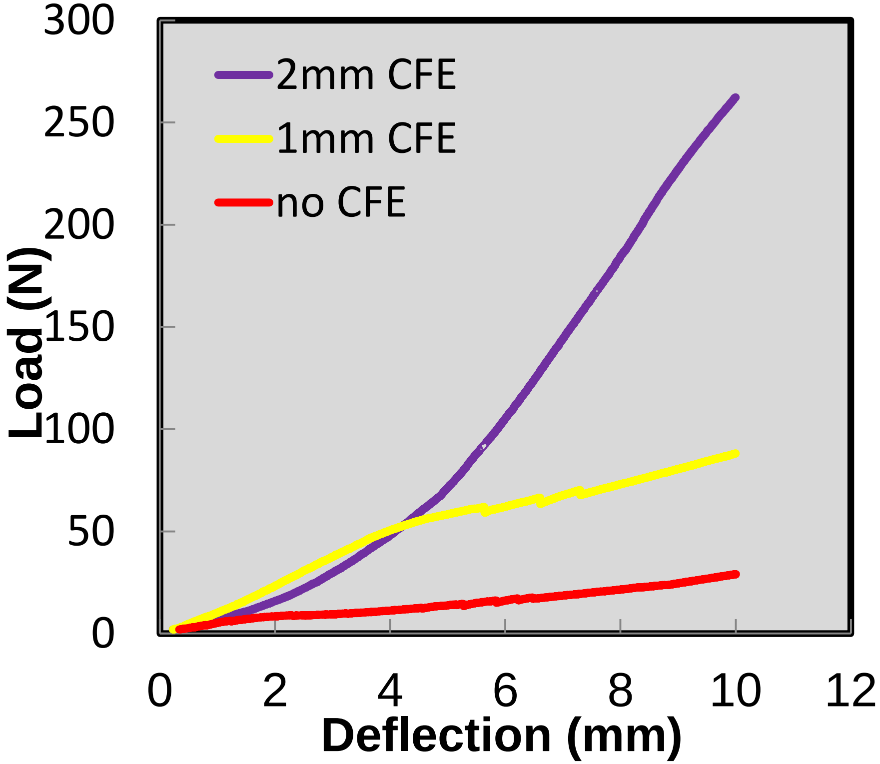




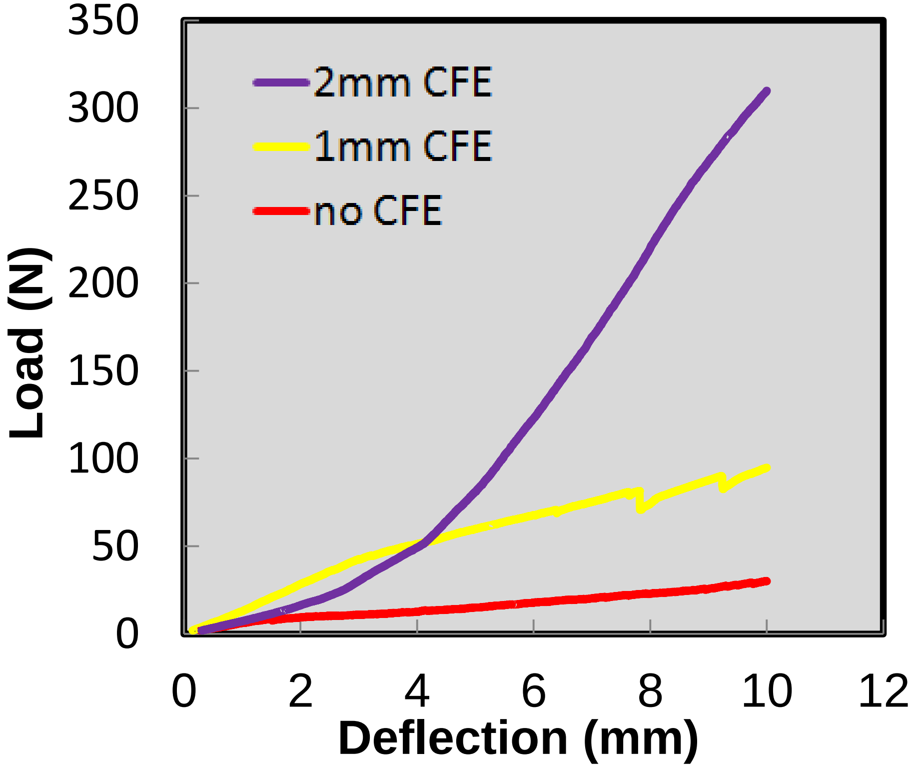
- Significant improvement in oil canning resistance with reinforcement
- Lower magnitude of load drop (lower sound magnitude) even with 1mm of reinforcement material

Experimental Results: Oil Canning Resistance

Stretch: 0.5%, 5080mm Radius



Stretch: 2%, 5080mm Radius



- No hard oil canning was observed for this sample, however the stiffness was substantially improved with reinforcement application